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Document Title <b>CAL EM Crystal Detector Element Specification</b>		

**Gamma-ray Large Area Space Telescope (GLAST)**  
**Large Area Telescope (LAT)**  
**Calorimeter Engineering Model**  
**Crystal Detector Element Specification**

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## CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes
D1	23 June 2001	CAL Peer Design Review – original version
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# 1 INTRODUCTION

## 1.1 PURPOSE

This document describes the requirements for the Crystal Detector Element (CDE) of the Calorimeter (CAL) derived from level IV detailed system requirements for the GLAST Large Area Telescope (LAT) Calorimeter (CAL).

## 1.2 SCOPE

This document is one level below the LAT-CAL Subsystem-Level-IV Specification LAT-SS-00210.

This specification captures the LAT overall requirements for the CDE. This encompasses the subsystem level requirements and the design requirements for the CAL.

## 1.3 APPLICABLE DOCUMENTS

Documents that are relevant to the development of the GLAST LAT Calorimeter CDE and its requirements include the following:

GE-00010	GLAST LAT Performance Specification
GEVS-SE	Goddard Environmental Verification Specification
433-MAR-0004	Mission Assurance Requirements (MAR) for the Large Area Telescope (LAT) Phase C/D/E, NASA Goddard Space Flight Center
NPD 8010.2B	NASA Policy Directive, Use of Metric System of Measurement in NASA Programs
LAT-SS-00010	LAT Performance Specification – Level II (b) Specification
LAT-SS-00018	LAT CAL Subsystem Specification - Level III Specification
LAT-SS-00210	LAT CAL Subsystem Specification – Level IV Specification
LAT-SS-00601	LAT Calorimeter Structure to CDE Interface Control Document
LAT-SS-00607	LAT Calorimeter CsI Crystal and CDE Handling Procedure
LAT-DS-00820	LAT Calorimeter CsI Crystal Performance Specification
LAT-DS-00072	LAT Calorimeter Engineering Model Dual PIN Photodiode Specification
LAT-PS-00798	Calorimeter Process Specification for Soldering Twisted-pair Interconnect Wires to the PIN Photodiodes
LAT-PS-00385	Calorimeter Process Specification for Bonding PIN Photodiode Assemblies to CsI Crystals
LAT-PS-00795	Calorimeter Process Specification for Wrapping CsI Crystals with VM2000 Optical Wrap
LAT-MD-00228	Calorimeter, Tracker, and Data Acquisition Contamination Control Plan

## 1.4 DEFINITIONS AND ACRONYMS

### 1.4.1 Acronyms

ACD	Anti Coincidence Detector
AFEE	Analog Front End Electronics of the CAL
CAL	Calorimeter subsystem of the LAT
CDE	Crystal Detector Element
DPD	Dual PIN photoDiode
GEVS	General Environmental Verification Specification
GLAST	Gamma-Ray Large Area Space Telescope
I&T	Integration and Test
LAT	Large Area Telescope
MAR	Mission Assurance Requirements
PDA	PhotoDiode Assembly
PEM	Pre-Electronics Module of the CAL
TBR	To Be Resolved

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### 1.4.2 Definitions

Analysis	A quantitative evaluation of a complete system and/or subsystems by review/analysis of collected data
Demonstration	To prove or show, usually without measurements of instrumentation, that the project/product complies with requirements by observation of the results.
Inspection	To examine visually or use simple physical measurement techniques to verify conformance to specified requirements.
Simulation	To examine through model analysis or modeling techniques to verify conformance to specified requirements
Testing	A measurement to prove or show, usually with precision measurement or instrumentation, that the product complies with requirements.
Validation	Process used to assure the requirement set is complete and consistent, and that each requirement is achievable.
Verification	Process used to ensure that the selected solutions meet specified requirements and properly integrate with interfacing products
$\gamma$	gamma ray
$\mu\text{sec}$ , $\mu\text{s}$	microsecond, $10^{-6}$ second
nm	nanometer
$\mu\text{m}$	micrometer
mm	millimeter
eV	electron Volt
MeV	Million electron Volt, $10^6$ eV
ph	photons

## 2 REQUIREMENTS

### 2.1 CDE CONCEPT

The Crystal Detector Element (CDE) is the detection unit of the calorimeter subsystem. It uses the scintillation properties of the CsI(Tl) to determine with excellent accuracy the energy deposited by interacting particles. The primary scientific characteristics of the CDE are the Light Yield, expressed in terms of electrons/MeV at the output of the read out system (photodiodes), and its position dependence.

### 2.2 DESIGN OVERVIEW

CsI crystals are wrapped in a reflective material to achieve high light collection efficiency and are read out by dual PIN photodiodes (DPDs) bonded to each end. An optical adhesive is used to bond the DPDs on the crystal end faces. The adhesive preserves the high light yield and mechanical stability required over the large design temperature range. The reflectivity of the wrapping is chosen to preserve high light yield, and the geometry of the wrap is chosen to permit insertion of completed CDEs into the mechanical structure. Two sets of twisted-pair wires are soldered to each DPD for connection to the front-end electronics. The four long corners of the crystal are chamfered and, along with the crystal end faces not covered with DPDs, are used for mounting surfaces within the mechanical structure. The CDE concept is shown in Figure 2-1.

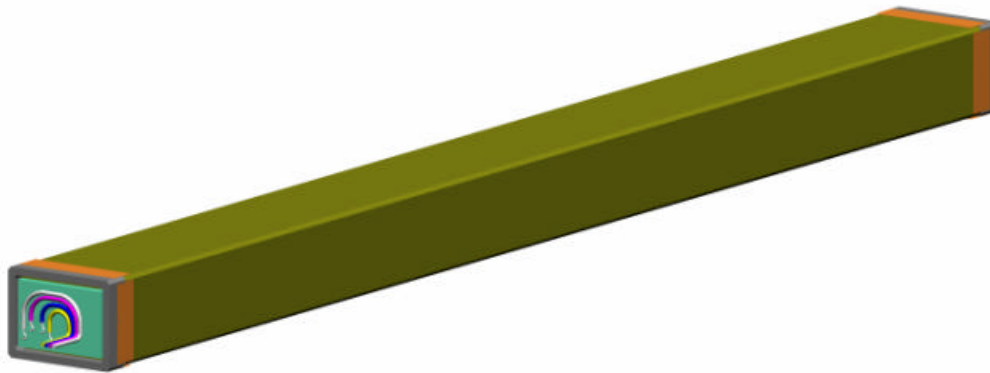


Figure 2-1 Crystal Detector Element Assembly

### 2.3 OPTICAL PERFORMANCE REQUIREMENTS

#### 2.3.1 *Absolute Light Yield*

The light yield produced by cosmic muons crossing within  $\pm 3$  cm of the center of the crystal shall be greater than 7000 electrons per MeV for the large diode and greater than 1100 electrons per MeV for the small diode [LAT-SS-00210 / 6.2.1 and 6.2.2].

This requirement shall be verified on all CDEs prior to shipment to the U. S.

#### 2.3.2 *Small to Large Diode Light Yield Ratio*

The ratio of light yields between the small and large diodes of each PDA shall be in the range 1/5 to 1/7 (nominally 1/6) for energy depositions within  $\pm 3$  cm of the central point of the crystal.

This requirement shall be verified on all CDEs prior to shipment to the U. S.

### **2.3.3 Energy resolution**

#### **2.3.3.1 Carbon Energy Resolution**

The energy resolution ( $1\sigma$ ) shall be better than 2% for high energy (100 to 1000 MeV/nucleon) Carbon ions of normal incidence at a central point in the crystal with a beam spot size < 3 mm diameter. [LAT-SS-00018-09, Sect. 5.3.4]

This resolution shall be tested in accelerator beams on the Engineering Model with flight or flight-like electronics. The remaining CDEs shall be verified by similarity.

#### **2.3.3.2 Muon Energy Resolution**

The energy resolution ( $1s$ ) shall be <8% for sea-level muons within  $\pm 3$  cm of the central point of the crystal.

This requirement shall be verified on all CDEs prior to shipment to the U.S. This verification shall be repeated by NRL on a sample of CDEs upon receipt, and it shall be performed on all CDEs at the PEM level. The resolution shall be deduced from the width of the distribution of the difference in signals of the two large diodes, as given in the following expression:  $\sigma(\mu) = \sigma(\text{Diff}) / \sqrt{2}$ , where  $\sigma(\mu)$  is the deduced energy resolution for muons as measured in a single large diode and  $\sigma(\text{Diff})$  is the measured rms of the distribution of normalized differences  $(P-M) / ((P+M)/2)$  in the signal from the large diodes of the Plus (P) and Minus (M) faces. This test may be performed with laboratory electronics of arbitrarily low noise performance.

#### **2.3.3.3 Thorium Energy Resolution**

The energy resolution (upper HWHM) shall be less than 6% for the 2.6 MeV photopeak of Thorium-228 within  $\pm 3$  cm of the central point of the crystal.

This requirement shall be verified on sample CDEs as appropriate to confirm the results of Paragraph 2.3.3.2. This test may be performed only at the CDE level. This measurement shall be made on the sum of signals from the two large diodes. This test may be performed with laboratory electronics of arbitrarily low noise performance.

### **2.3.4 Light Yield Asymmetry**

The change in light asymmetry measure shall be between 0.15 and 0.40 for muon or thorium energy depositions at  $\pm 12$  cm from the center of the crystal. The asymmetry measure is defined as the ratio  $(P-M) / (P+M)$ , where P = signal in large diode at the "plus" end and M = signal in large diode at "minus" end. [Derived from LAT-SS-00210, Sect. 6.4.6. Consistent with light tapering satisfying Sect. 2.3.5 in LAT-SS-00239.]

This requirement shall be verified on all CDEs prior to shipment to the U. S.

### **2.3.5 Light Tapering**

The dependence of light yield in the large diode on the position of energy deposition along the crystal shall be monotonic and such that with a thorium source or muons 2 cm from one crystal face, the light collected at the far end is  $70\% \pm 10\%$  of the light collected by the large diode close to the source or muons. [Derived from LAT-SS-00210 / 6.4.6, accounting for change from Tyvek to VM2000 wrap.]

This requirement shall be verified on all CDEs prior to shipment to the U. S.

### **2.3.6 Light Yield Uniformity**

The full range of dispersion (i.e. FWZI) in absolute light yield values for all CDEs intended for a single Module shall be smaller than 25%.

This requirement shall be verified on all CDEs prior to shipment to the U. S. The CDEs and any spares intended for a single Module shall be compared one to another. CDEs for distinct Modules need not comply with this requirement.

### 2.3.7 Mission life

Performance of the CDE shall not change by more than 40% over the mission life. This shall be demonstrated on sample CDEs via thermal and radiation hardness qualification tests.

### 2.3.8 Verification

All optical performance requirements shall be met between 19°C and 25°C, except for tests designed specifically to test performance at other temperatures. CDEs shall satisfy the optical performance requirements within this temperature range.

Tests of the optical performance of CDEs shall be made with CR-RC shaping with 3.5  $\mu$ s time-to-peak. This configuration has been chosen to simulate the characteristics of the flight shaping amplifiers.

## 2.4 CDE COMPOSITION

Each CDE shall be composed of the following parts :

- A CsI scintillation crystal, which is a rectangular parallelepiped with a chamfer on the corners of the long dimension
- Two Photodiode Assemblies (PDAs), one bonded to each end of the CsI crystal. Each PDA consists of:
  - One Dual PIN photoDiode (DPD)
  - Two sets of twisted-pair interconnect wires attached to the leads of the DPD
- Optical bonds attaching the DPD assemblies to each CsI crystal end using an optical bonding adhesive
- Optical Reflective Wrap – A reflective material covering the 4 crystal sides and chamfered corners
- ID Label – A label imprinted with the CDE serial number
- Molded End Caps – Attached over bonded PDAs and optical reflective wrap at both ends of the crystal to close out the ends of the CDE

### 2.4.1 CsI (TI) Crystal

The CsI crystals shall comply with the optical and mechanical specifications given in the Calorimeter CsI Crystal Performance Specification, LAT-DS-00820. The CsI crystal is shown in Figure 2-2.

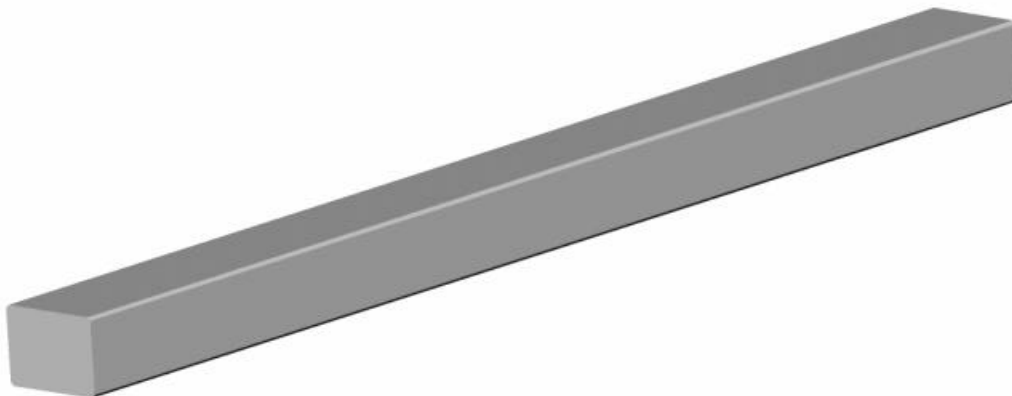


Figure 2-2 CsI Crystal

### 2.4.2 Photodiode Assembly

The PhotoDiode Assembly (PDA) is comprised of twisted-pair interconnect wires soldered and staked to a Dual PIN Photodiode. Figure 2-3 shows the orientation of the interconnect wires and staking on the Dual PIN Photodiode.

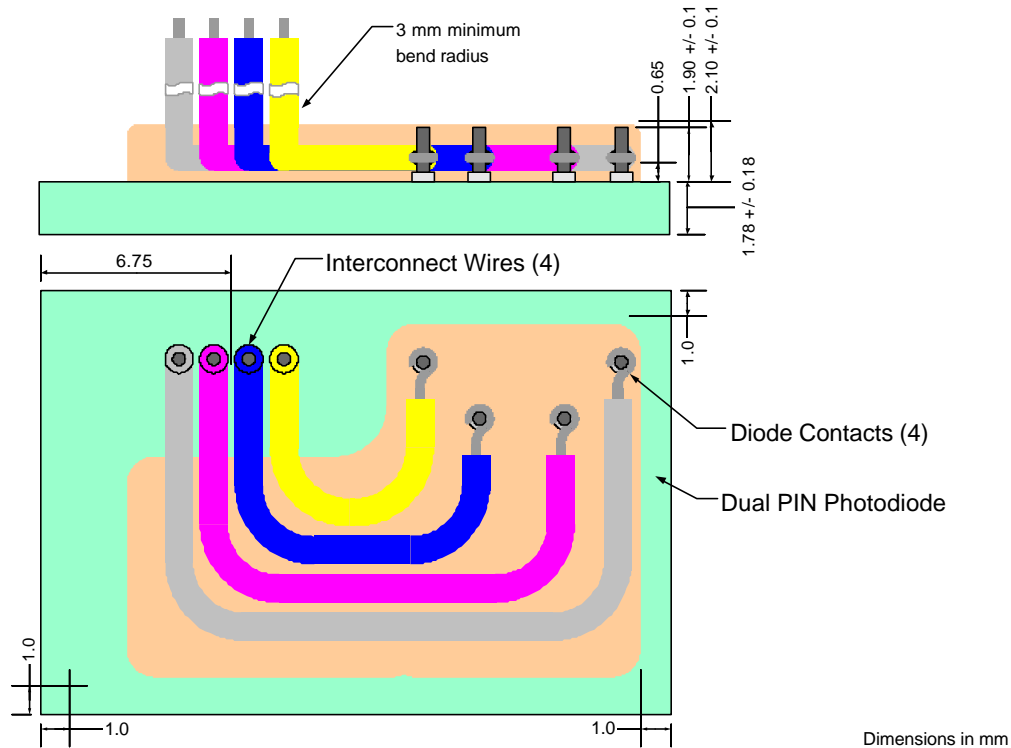


Figure 2-3 DPD with Interconnect Wires Installed

#### 2.4.2.1 Dual PIN Photodiode

The Dual PIN photoDiode (DPD) shall comply with the specifications in the Calorimeter PIN Photodiode Assembly Specification, LAT-DS-00072.

#### 2.4.2.2 Twisted-pair Interconnect Wires

The twisted-pair interconnect wires shall be soldered and staked in accordance with the Calorimeter Process Specification for Soldering Twisted-pair Interconnect Wires to the PIN Photodiodes, LAT-PS-00798. Each wire shall be sized to 150 mm in length prior to stripping.

### 2.4.3 Crystal – PDA Bonding

#### 2.4.3.1 Bonding Specification

The PDAs shall be bonded to the crystal ends with an optically transparent adhesive (Dow Corning DC 93-500 with primer Dow Corning DC 92-023) that maintains optical and mechanical performance over the qualification temperature range and under qualification mechanical test levels of the CAL module.

The bond thickness shall be  $0.7 \pm 0.1$  mm. Bond material shall not extend beyond the footprint of the PDA on the crystal end face. This bonding shall be performed in accordance with the Calorimeter Crystal to PDA Bonding Process Specification, LAT-PS-00385.

#### 2.4.3.2 PDA Positioning on the Crystal

The PDAs shall be positioned on the CsI crystal end faces such that they will not contact the end cap. This results in positioning of the PDAs on the crystal end faces with the dimensions and tolerances shown in

Figure 2-4. Note that for reference purposes, the “top” surface of the crystal is identified with a scribe mark as detailed in the CsI Crystal Performance Specification, LAT-DS-00820. The PDA location shall be referenced from the “top” and “left” crystal surfaces, when viewed end on, as indicated in Figure 2-4. Note also the location of the four diode pins in relation to the positioning surfaces of the crystal. When viewed from either end of the crystal, the diode pins shall be located in the upper right quadrant.

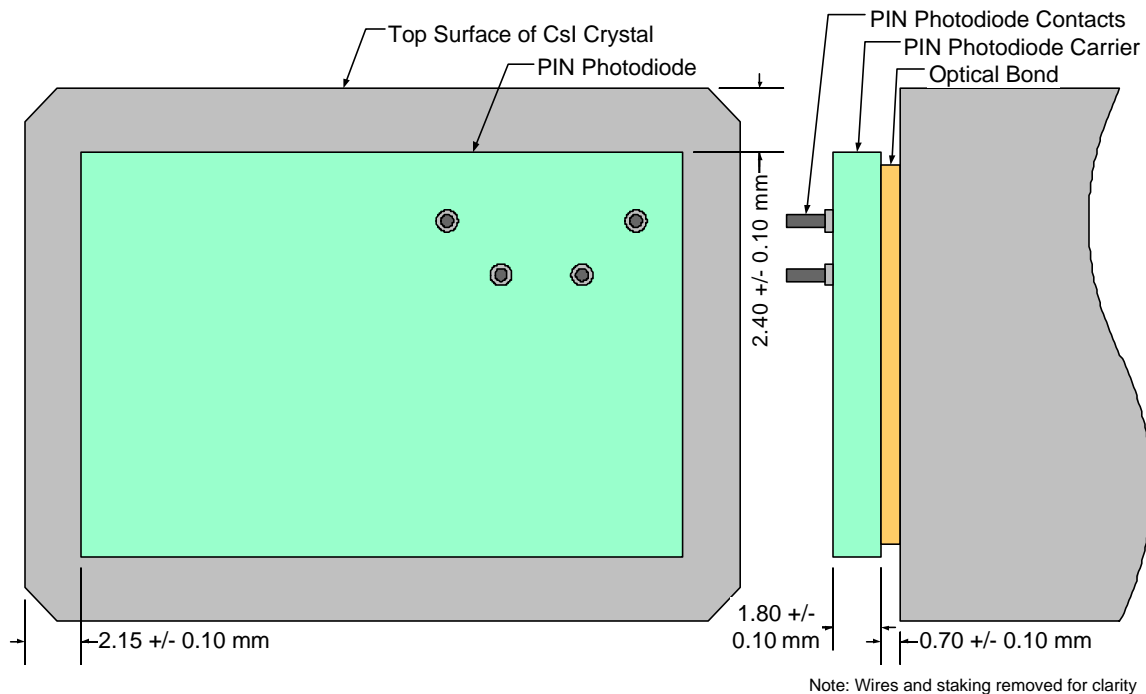


Figure 2-4 PDA Positioning on Crystal End

#### 2.4.4 Optical Reflective Wrap

The crystal shall be wrapped in reflective material (3M Corp. VM2000) to meet the optical specifications defined herein and mechanical specifications for easy insertion within the Calorimeter mechanical structure. The wrapping shall be performed in accordance with the CDE Wrapping Procedure, LAT-PS-00795. The orientation of the optical reflective wrap on the bonded crystal is shown in Figure 2-5.

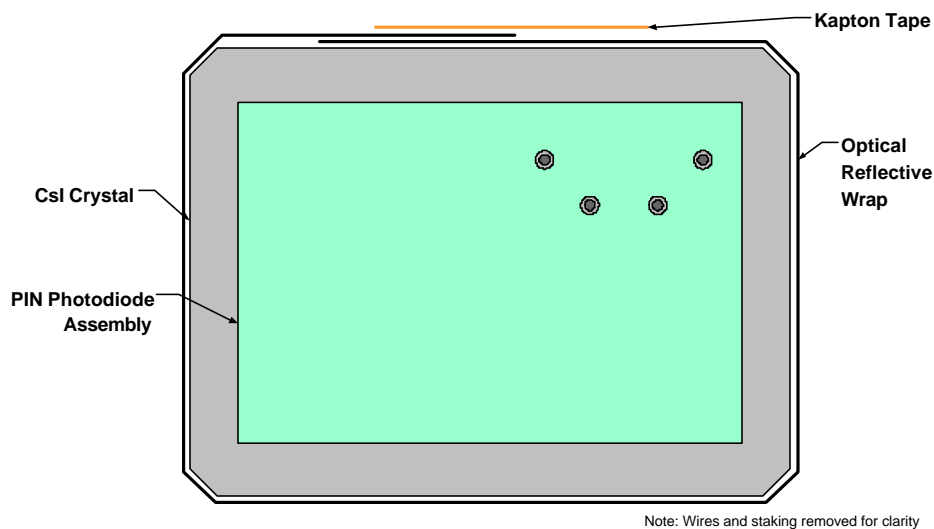


Figure 2-5 Optical Reflective Wrap Orientation on CsI Crystal

### 2.4.5 Molded End Caps

The bonded crystal wrapped with reflective material shall be closed out by attaching molded end caps at both ends. The end cap attachment shall be performed in accordance with the CDE Wrapping Procedure, LAT-PS-00795. Figure 2-6 shows a picture of the molded end cap. Figure 2-7 shows the application of the end cap on the finished CDE end.

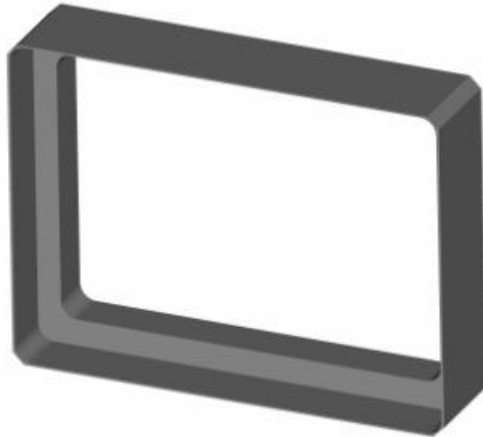


Figure 2-6 Molded End Cap

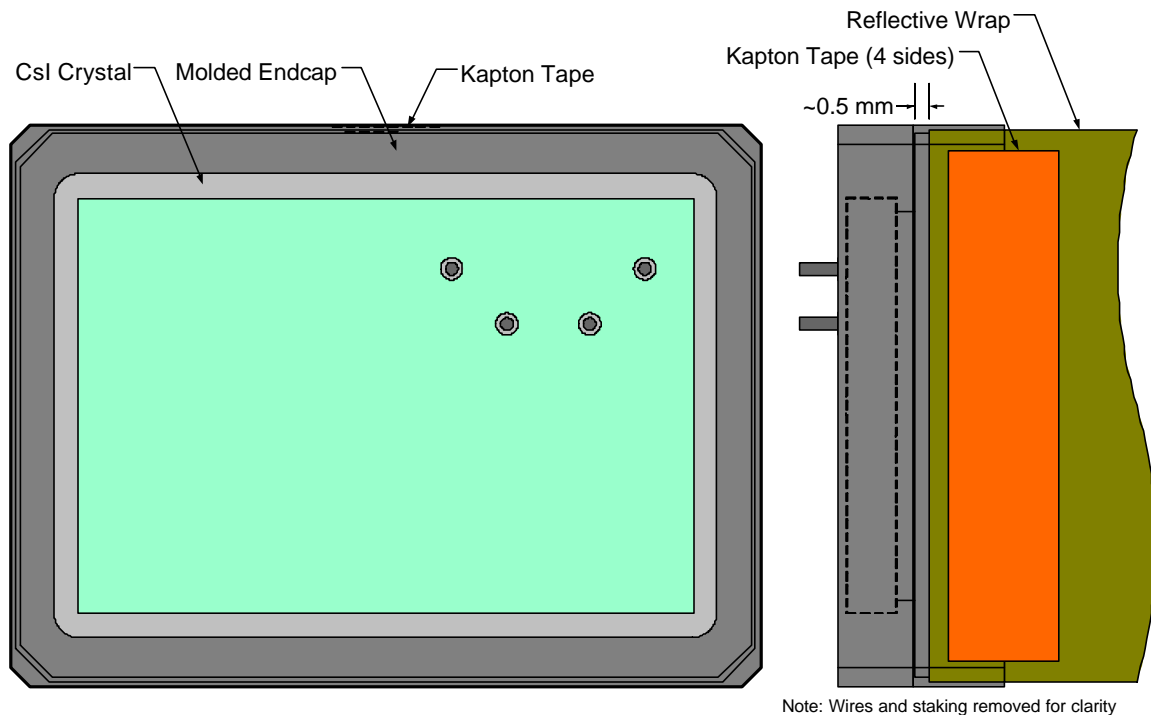


Figure 2-7 End Cap on CDE End

## 2.4.6 MECHANICAL SPECIFICATIONS

### 2.4.6.1 Overall Envelope

Each CDE shall have overall dimensions (including bonded PDAs and Optical Reflective Wrap) not to exceed those given in Table 2-1. The “CDE Total Length” is defined as the distance between the ends of the DPD pin contacts on opposite faces of the crystal, not including the extent of the twisted-pair interconnect wires. These dimensions allow for a minimum 0.1 mm clearance between the CDE and the structure cell walls.

Table 2-1 CDE Dimensions

Parameter	Maximum Value (mm)	Minimum Value (mm)
Crystal Length	326.00	325.40
Bonding Thickness	0.80 (x2)	0.60 (x2)
DPD Carrier Thickness	1.96 (x2)	1.60 (x2)
DPD Pin Contact Length	2.00 (x2)	1.80 (x2)
<b>CDE Total Length</b>	<b>335.52</b>	<b>333.40</b>
CDE End Cap Thickness (see note)	2.9 (x2)	2.7 (x2)
<b>CDE Cap-to-Cap Length</b>	<b>333.40</b>	<b>332.00</b>
Crystal Height	19.90	19.50
Kapton Tape	0.002	0.002
Wrapping Thickness	0.13 (x3)	0.13 (x3)
<b>CDE Total Height</b>	<b>20.29</b>	<b>19.89</b>
<b>CDE End Cap Height (see note)</b>	<b>20.35</b>	<b>20.30</b>
Crystal Width	26.70	26.30
Wrapping Thickness	0.13 (x2)	0.13 (x2)
<b>CDE Total Width</b>	<b>26.83</b>	<b>26.43</b>
<b>CDE End Cap Width (see note)</b>	<b>27.20</b>	<b>27.15</b>
Distance between Opposing Chamfers	31.78	31.58
Wrapping Thickness	0.13 (x2)	0.13 (x2)
<b>Total Chamfer Distance</b>	<b>32.04</b>	<b>31.84</b>

Note: Also included in Table 2-1 are the dimensions for the molded end cap that is to be used to close out the wrapping of the CDE. Since the DPD Pin Contact length protrudes through the end cap, the use of the end cap does not affect the total length of the CDE. Even though the height and width of the End Cap are larger than the wrapped crystal, the CDE Total Height and Width values are the important dimensions for CDE Verification.

### 2.4.6.2 CDE Mass

The mass of each CDE, including CsI crystal, DPDs, optical bonds, twisted-pair interconnect wires, optical reflective wrap, and molded end caps shall not exceed 0.80 kg, summarized in Table 2-2.

Table 2-2 CDE Mass Summary

Component	Quantity	Unit Mass (kg)	Total Mass (kg)
CsI Crystal	1	0.7850	0.7850
Dual Photodiodes	2	0.0016	0.0032
Optical Bonds	2	0.0002	0.0004
Interconnect Wires	8	0.0002	0.0016
Staking	2	0.0008	0.0016
Optical Reflective Wrap	1	0.0033	0.0033
Molded End Caps	2	0.0014	0.0014
<b>TOTAL</b>			<b>&lt;0.80</b>

## 2.5 IDENTIFICATION AND MARKING

### 2.5.1 CDE Unique Identification (ID) Code

Each CDE shall be uniquely identified by the serial number of the CsI crystal that was used in the assembly.

This identification code is not visible after integration with the structure. Therefore, this identification code shall be entered into a database that serves as a record of the location of each CDE within the structure and the identifying numbers of the component CsI crystals and DPDs comprising the CDEs.

### 2.5.2 CDE Marking

Each CDE shall be marked with its Unique ID Code and an orientation mark on a label attached to the top surface of the completed CDE (the surface with the Kapton tape sealing the wrapper). The orientation mark shall be “(+)”, to indicate the “Plus” face of the completed CDE. As shown in Figure 2-8, the label shall be located so that the serial number reads from left to right, with the right edge of the label within 25 mm of the fiducial “V” on the crystal. The total length of the label shall be less than 50 mm. The CsI Crystal Performance Specification, LAT-DS-00820, utilizes the fiducial “V” to identify the “top” surface and the “plus” end (which is the “right” end) of the crystal.



Figure 2-8 Sample CDE Identification Label

## 2.6 ENVIRONMENTAL REQUIREMENTS

### 2.6.1 Thermal and Mechanical Environments

The CDEs shall be designed and manufactured to operate within the thermal and mechanical environments specified in the LAT CAL Level-IV Specification, LAT-SS-00210, Section 8.0, Thermal, and Section 11.0, Environmental.

### 2.6.2 Outgassing and Contamination

All materials used in the CDE shall meet the outgassing and contamination requirements specified in the Calorimeter, Tracker, and Data Acquisition Contamination Control Plan (LAT MD-00228).

### 2.6.3 CDE Handling Procedures

CDEs shall be stored, handled, and shipped using controlled procedures that guarantee minimum exposure to structural and mechanical loads and prevent exposure to moist or damp surfaces and environments. These are described in the Crystal and CDE Handling Procedure (LAT-SS-00607).

## 2.7 QUALITY ASSURANCE PROGRAM REQUIREMENTS

The CDE supplier shall implement a QA program whereby assurance is given that:

- For each configuration item (i.e., PIN photodiode soldering to interconnect wires, bonding, wrapping, etc.) there is a defined and implemented qualification approach that makes it possible to demonstrate that the item is so designed and assembled that it will perform satisfactorily in the intended environment
- The approach adopted guarantees that the design is producible, repeatable, and verifiable and that the resulting product can be verified and operated within the required operating limits
- Adequate controls verifiable by QA are established for the procurement of PIN photodiode, interconnect wires, bonding, wrapping, crystals, materials, etc
- Fabrication, assembly, test and maintenance are conducted in a controlled manner so that the end item conforms to the applicable NRL approved procedures and test methods
- Quality records are maintained and analyzed so that trends can be detected and reported in time to enable preventive/corrective actions to be taken using the database system
- Procedures and instructions are established which provide for the identification, segregation, handling, packaging, preservation, storage and transportation of all items
- The supplier shall prepare, maintain, and implement a plan of the QA activities, in accordance with the requirements in the MAR, GSFC-433-MAR-0004, and will be submitted for approval. The plan may be part of the overall project Product Assurance Plan
- The supplier shall periodically prepare and submit to NRL, reports on the status and progress of the QA program, as part of the overall PA reporting
- The supplier shall establish a documented training program for personnel whose performance determines or affects product quality. Operators performing critical processes such as soldering, bonding, and handling of crystals shall be trained and certified by internal or external training programs accepted by NRL, or are able to demonstrate a regular and satisfactory use of the related skills
- The supplier shall perform systematic audits on all activities defined herein their own performance and supplier's to verify the implementation and effectiveness of the provisions defined in the QA Program Plan. NRL shall have the right to be represented in the planned external audits. For this purpose, the external audit schedule shall be supplied to NRL and updated regularly
- The supplier shall implement a traceability system, which shall be maintained throughout all phases of the project and during the planned operational life of the Calorimeter
- The supplier traceability system shall provide for the ability to:
  1. Establish bi-directional and unequivocal relationship between CDE parts / materials / products and associated documentation / records
  2. Trace data, personnel and equipment related to procurement, fabrication, inspection, test, assembly, integration, and operations activities
  3. Trace backwards the location of materials, parts, and subassemblies
- A unique and permanent part or type number shall identify each part, material or product

- The supplier shall control, calibrate and maintain inspection, measuring and test equipment, whether owned by the supplier, or on loan to the supplier, to demonstrate the conformance of CDE to the specified requirements
- The supplier shall establish and maintain a nonconformance control system. The system shall provide for a disciplined approach to the identification and segregation of nonconforming items, the recording, reporting, review, disposition and the definition and implementation of corrective actions. Nonconformances or Problem Reports shall be classified as red (major), yellow (minor) or green (none) on the basis of the severity of their consequences. All nonconformance reports will be emailed within 24 hours of its origination
- The supplier shall prevent handling damage during all phases of manufacturing, assembly, integration, testing, storage, transportation and operation, by adequate protection of items during handling; by handling devices; and procedures and instructions
- The supplier shall have secure storage areas available for incoming materials, intermediate items during process needing temporary storage, and end items before shipping
- The processes designed and developed shall be reproducible and have proven repeatability of its performances and characteristics
- Inspection and test requirements, including acceptance/reject criteria, shall be developed and expressed in an unambiguous and quantified manner
- The supplier shall implement a QA program to assure that satisfactory provisions are defined and implemented in order to verify that the requirements are met, specifically:
  1. Requirement verification is performed progressively, as each stage of the manufacturing is completed, and provides the organized base of data upon which qualification and acceptance will be incrementally declared
  2. Top-down requirement allocations and bottom-up requirement verifications are complete and consistent
  3. A system for tracking requirements and verification of results is established and maintained during the completion of requirements specified herein
  4. Verification methods are adequate and consistent with the type and criticality of the requirements
  5. Appropriate reference to the verification documentation is recorded and status updated at project reviews up to final acceptance
- Inspection and test requirements are expressed in an unambiguous and quantified manner including test sequence; test conditions; test standards, if any; applicable test levels, duration and tolerances; and accuracy in measurement
- The qualification and screening test procedures and facilities are defined, approved, and released

### **3 CDE RESPONSIBILITIES**

(For reference only. Please refer to applicable Memoranda of Agreement and other international documents.)

#### **3.1 CsI(Tl) CRYSTALS**

The CsI crystals shall be procured and verified from Sweden according to the Calorimeter CsI Crystal Performance Specification, LAT-DS-00820.

#### **3.2 DUAL PIN PHOTODIODES (DPD)**

The procurement of DPDs is a shared responsibility of NRL and CEA. The qualification, screening, test, and bonding to the crystal ends shall be the responsibility of CEA.

### **3.3 TWISTED-PAIR INTERCONNECT WIRES**

The twisted-pair interconnect wire procurement, qualification, test and attachment to the DPDs shall be the responsibility of CEA.

### **3.4 DPD – CSI CRYSTAL OPTICAL BOND**

The DPD – CsI Crystal optical bond process qualification, test and implementation shall be the responsibility of CEA.

### **3.5 OPTICAL REFLECTIVE WRAP**

The procurement and application onto the CsI crystals of the Optical Reflective Wrap shall be the responsibility of CEA.

### **3.6 MOLDED END CAPS**

The procurement of the Molded End Caps shall be the responsibility of IN2P3/Ecole Polytechnique. The application of the Molded End Caps onto the CsI crystals shall be the responsibility of CEA.

### **3.7 GROUND SUPPORT EQUIPMENT**

With the exception of the Crystal Optical Testing Station, Ground Support Equipment required for the CDE production and testing – including assembly fixtures and jigs, shall be the responsibility of CEA.

## **4 VERIFICATION REQUIREMENTS**

This contents of this section are TBD. This section will be updated as the verification requirements evolve.